Identification and study of performance of controllers on Heat Exchanger

Thesis submitted in partial fulfilment of the requirements for the degree of

Master of Technology

in

Electronics and Communication Engineering

(Specialization: *Electronics and Instrumentation*)

by

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Rourkela, Odisha-769008

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Under the Supervision of

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CERTIFICATE

This is to certify that the Thesis Report entitled **— "Identification and study of performance of controllers on heat exchanger"** submitted by **Mr. G Santhosh kumar** bearing roll no. **213EC3217** in partial fulfilment of the requirements for the award of Master of Technology in Electronics and Communication Engineering with specialization in **"Electronics and Instrumentation Engineering"** during session 2013-2015 at National Institute of Technology, Rourkela is authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University / Institute for the award of any Degree or Diploma.

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Date:

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ABSTRACT

This work is concerned with the identification of transfer function models for heat exchanger using system identification by selecting linear parametric models ARX, ARMAX, and according to the process requirement product temperature of the heat exchanger system has to be maintain at a desired set point. For this, firstly some conventional controllers like standard PID, Feed Forward with the feedback PID, IMC, and internal model based PID controllers were used. For the design of Feed Forward controller considered the disturbances as variation of the input flow. Due to some lower performance specifications and slow response time of conventional control techniques, intelligent controllers like fuzzy PID controller and FOPID controller using PSO algorithm are developed. These intelligent controllers maintains the temperature of the outlet fluid at a desired set point in the shortest possible time regardless of process disturbances, load, device saturation and nonlinearity.

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LIST OF ACRONYMS USED

ARX	-	Auto Regression Exogenous
ARMAX	-	Auto Regression Moving Average Exogenous
FOPDT	-	First Order plus Delay Time model
PID	-	Proportional Integral Derivative Controller
Z-N	-	Zeigler-Nichols tuning method
FF	-	Feed Forward controller
IMC	-	Internal Model Controller
IMC PID	-	Internal Model based Proportional Integral Derivative Controller
FOPID	-	Fractional Order PID controller
PSO	-	Particle Swarm Optimization
FLC	-	Fuzzy Logic Controller
ISE	-	Integral Square Error
IAE	-	Integral Absolute Error
ITAE	-	Integral of Time multiplied by Absolute Error

CHAPTER I

Introduction

1.1 Overview

Mathematical model of a system is necessary for further processing and control of a system, for example in control systems using state space model to find transfer function we require a mathematical model of each component of that system. System identification is the procedure of finding mathematical model for the dynamic system. System identification uses some simple mathematical rules to find the mathematical model of the system based on input output data. It involves analyzing, processing, identification of the system from the acquired data for the parameter estimation of the system. System is the unit which gives the outputs from the inputs by doing some operations. Dynamic system is a system whose response varies with time, it means the output value depends not only on the present inputs but also on the previous inputs values.

A heat exchanger is a device used to transfer the heat between different mediums which are at different temperatures and the two mediums may be in a contact or separated by a solid wall, here the medium may be a solid particles or a fluid. In heat exchangers, for an efficient heat transfer we prefer the large area of a tube. Shell and tube exchanger is the type of heat exchanger widely used in industries as it can withstand higher pressures.

Transfer function of the heat exchanger is developed from the input and output data of heat exchanger system using system identification method. A class of conventional and intelligent controllers are applied to the heat exchanger and studied the performance of various controllers in terms of some performance criteria like time response specifications.

1.2 Literature review

J. A. Ramos1 and P. Lopes dos presents mathematical modeling, system identification of a two tank system from the basic first principle methods and the design of microprocessor based intelligent controller for the modeled system [1].

Subhransu Padhee and Yaduvir Singh presents comparative analysis of different control strategies implemented on heat exchanger. Which includes PID using Z-N tuning methods, Feed Forward controller and the Fuzzy PID intelligent controller [2].

Mahmud Iwan Solihin, Lee Fook Tack presents tuning of PID controller using Particle Swarm Optimization (PSO). Tuned the PID parameters with the PSO algorithm and compared with the Z-N based tuning method for the DC motor system [3].

1.3 Motivation

Modelling and controlling the temperature of the heat exchanger system is chosen because of its wide application in industrial control systems like oil refinery etc. TEMPERATURE control is an important task in process control industries, e.g., chemical plants, air conditioning, and petroleum refineries etc. The main challenge while designing the controller for temperature controlling processes are to avoid overheating and to maintain the desired temperature set point level against process disturbances and some environmental variations.

1.4 Objectives

The main objectives of this work are

i. Modelling and identification of the heat exchanger system.

ii. Temperature control of heat exchanger system.

iii. Study of performance of different controllers on temperature control of heat exchanger.

iv. Performance evolution of intelligent controllers with the conventional controllers.

1.5 Thesis organization

This thesis is well organized into five chapters including the introductory chapter. The coming four chapters are

Chapter2: Modeling and identification of the heat exchanger.

The heat exchanger is mathematically derived from the system identification method from the input output data. First order delay time transfer function for the process is derived using system identification method.

Chapter 3: Design of conventional controllers

This chapter describes the design of some conventional controllers like standard PID, Feed forward with Feedback PID, IMC, IMC-PID controller. Designed the PID controller using Zeigler-Nichols, Cohen-coon tuning methods. Feed forward controller is designed by considering the disturbance flow variation of input. IMC controller designed by considering process model transfer function as the original transfer function.

Chapter 4: Design of Intelligent controllers

With the conventional controllers we may not get the desired results. Here in this chapter designed the Fuzzy based PID controller using some fuzzy logic principles, and also designed the Fractional order PID controller using PSO (particle swarm optimization) technique. PSO is applied to tune the parameters of FOPID controllers considering min error as objective function.

Chapter 5: Conclusion

This part represents the overall work and research in brief. It also represents the better control technique. It compares the results of an intelligent controller with the conventional controllers in terms of some performance indices like rise time, settling time etc. It also focuses on the future working areas which can be continued for this work.

CHAPTER II

Identification of transfer function model of heat exchanger

2.1 System identification

Mathematical model of a system is necessary for further processing and control of a system, for example in control systems using state space model to find transfer function we require a mathematical model of each component of that system.

There are three ways for finding the system mathematical model

1. **White box modelling**

   This model is used when we have a sufficient knowledge about the system. It uses some first principles to derive the mathematical modelling of the system by taking the relation between small components in the system. It is used in some electrical, mechanical systems where we can predict the system mathematical model from simple physical laws.

2. **Black box modelling**

   This model is used when we didn't have any information about the system. Here the only way to find the mathematical model by system behavior i.e. the input-output data. By giving some input we will get some output data by considering this input-output data we will calculate the mathematical model of that particular system.

System identification is the process of finding mathematical model for the dynamic system. It is concerned with the black box modelling. System identification uses some simple mathematical rules to find the mathematical model of the system from the input output data. It involves analyzing, processing, identification of the system from the acquired data for the parameter estimation of the system.

2.2 System Identification Procedure

The mathematical model of the system is determined by the data obtained from the experiment and the knowledge about the system. Identification procedure needs a proper input to be applied, conducting experiment, and the response of the system is measured. Collect the input-output data for design of mathematical model.

System identification involves in following steps

1. **Collecting the data:** By applying the suitable input the output of the system can be found. The resultant input-output data is collected. And then for removing the noise we apply some preprocessing steps like filtering, scaling etc.
2. **Model selection:** Selection of model is important task in the system identification procedure. Select the model structure from the list and then the data is fitted into that model structure. Here some of the parametric linear model structures are ARX, ARMAX etc.
3. **Parameter estimation:** Then we have to find the selected model structure parameters, for this we use least squares method. Least square parameter estimation method is the minimization of squares of the difference between the actual value and the measured value.
4. **Model validation:** Estimated model is validated by means of FIT%

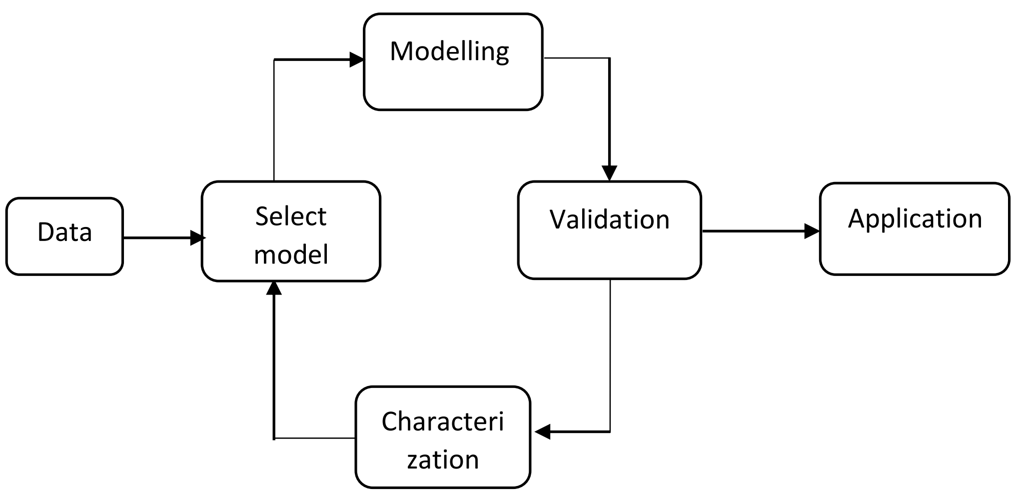


Fig.1: Block diagram of System identification procedure

2.3 Heat Exchanger

Heat exchanger is an equipment that exchanges the thermal energy between two or mediums which are in a direct or indirect contact. Here the medium may be fluid or solid particles. These are mainly used in chemical plants and some process control industries. Our main aim is to control the temperature of the product.

There are mainly two types of heat exchangers

1. Parallel flow heat exchangers: In this type of heat exchangers two fluids enters at the same end and they move parallel in the same direction.
2. Counter flow heat exchangers: in this type of heat exchangers two fluids enters in the opposite sides and they move opposite to each other. These are more effective than the parallel flow heat exchangers.

Main aim of this paper is find the transfer function model of heat exchanger by the system identification procedure. For this first we have to collect the input-output data.

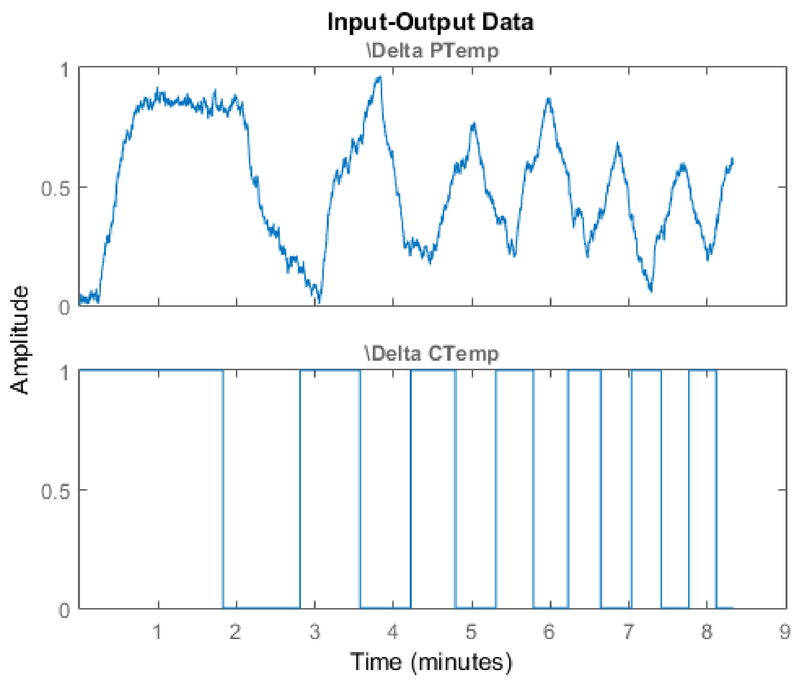


Fig.2: Input-output data of heat exchanger

Next step is select the model and this data is fitted to the selected model. In this case we first selected the ARX model and then ARMAX model by the least squares method we estimated the parameters and then calculated the Fit%.

As shown in the Fig. by the ARX model we got the first order delay time transfer function with the Fit% as 36

$$G_p(s) = \frac{2.94}{s+3.302} e^{-0.287s}$$

Whereas by using ARMAX model obtained transfer function model has 68.28 Fit%.

$$G_p(s) = \frac{1.468}{s+1.561} e^{-0.0483s}$$

So we are considering the ARMAX model as the best model

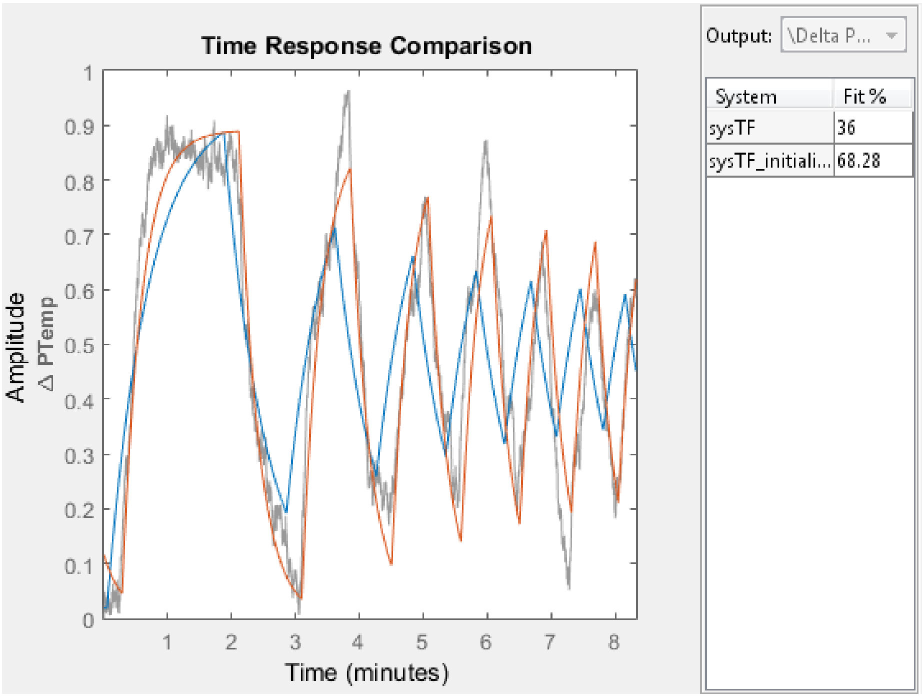


Fig.3: ARX, ARMAX model output for the Heat exchanger

CHAPTER III

Design of conventional controllers

In this chapter we designed different controllers like PID using Ziegler-Nichols, Cohen-coon tuning rules, PID with Feed-Forward, IMC and IMC-PID controllers for the heat exchanger for a better performance and good disturbance rejection.

3.1 PID Controller

Proportional Integrating Derivative controller is widely used in industrial control systems because of its simplicity. PID controller measures the difference between a measured process variable and a desired set- point as error. The PID controller minimizes the error by adjusting the process inputs. Here the controller parameters P vale depends on present error I value depends on accumulation of past errors D value is a prediction of future errors. It does not depends on the knowledge of the process, it only depends on the process variable which makes the controller makes most useful.

The PID controller is described in as

$$G_c(s) = K_p e(t) + K_i \int_o^t e(t)dt + K_d \frac{de}{dt} \qquad \ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

Where $G_c(s)$ is the controller output, e(t) is the error, and t is the sampling time. K_p, K_i and K_d are the proportional, integral and derivatives gains (or parameters) respectively that are to be tuned.

The process of tuning is nothing but finding appropriate parameters for the PID controller. Tuning determines the overall performance of controller which determines the quality of product, cost etc. the response of the controller measured by measuring the response of the controller to an error.

A small proportional gain results in a slow control action, but minimizes the overshoot. Whereas the large proportional gain may have fast response action but the output response is damping. Integral term corresponds to minimize the steady state error. And the derivative action increases the stability an also settling time of the system.

- Zeigler Nichols tuning method is based on the open loop step response of system. To find the P, I, D parameters using Z-N method first find the open loop step response and from that process reaction curve determine the dead time t_d, time constant τ, and ultimate value that the response reaches at steady state K are used to set the P, I, and D gains depending on the type of controller used

Controller	K_c	τ_i	τ_d
P	$\frac{\tau}{t_d K}$	∞	0
PI	$0.9\frac{\tau}{t_d K}$	$3.33t_d$	0
PID	$1.2\frac{\tau}{t_d K}$	$2t_d$	$0.5t_d$

Table 1: Ziegler-Nichols open-loop tuning rule

Obtained transfer function of PID controller by following the above procedure is

$$G_c(s) = 17.064(1 + \frac{1}{8.096s} + 0.015s)$$

i.e. for to design the PID controller

$K_p = 17.064$

$K_i = 2.107$

$K_d = 0.259$

- Cohen& coon method of tuning is used for first order plus dead time processes due to controller does not respond instantaneously to the disturbances. This method increases the speed of the steady state response given by the Ziegler Nichols tuning method for large time delay processes.

Controller	K_c	τ_i	τ_d
P	$\frac{1}{K}\frac{\tau}{t_d}(1+\frac{t_d}{3\tau})$	∞	0
PI	$\frac{1}{K}\frac{\tau}{t_d}(0.9+\frac{t_d}{12\tau})$	$\frac{t_d(30+3\frac{t_d}{\tau})}{9+20\frac{t_d}{\tau}}$	0
PID	$\frac{1}{K}\frac{\tau}{t_d}(\frac{4}{3}+\frac{t_d}{4\tau})$	$\frac{t_d(32+6\frac{t_d}{\tau})}{13+8\frac{t_d}{\tau}}$	$t_d\frac{4}{11+2\frac{t_d}{\tau}}$

Table 2: Cohen& coon open-loop tuning rule

According to the above Cohen and coon controller settings PID controller in continuous time is

$$G_c(s) = 19.05(1+\frac{1}{2.38s}+0.017s)$$

i.e. for to design the PID controller

$K_p = 19.05$

$K_i = 8.004$

$K_d = 0.3238$

3.2 Feed forward plus Feedback PID Controller

Feed forward control is used in control systems design applications when we have knowledge about the process or controlled variable, it means the first principal equations which are describing the process are known. We cannot employ the only feed forward control, usually for good performance combination of Feedback and Feed forward approaches is used.

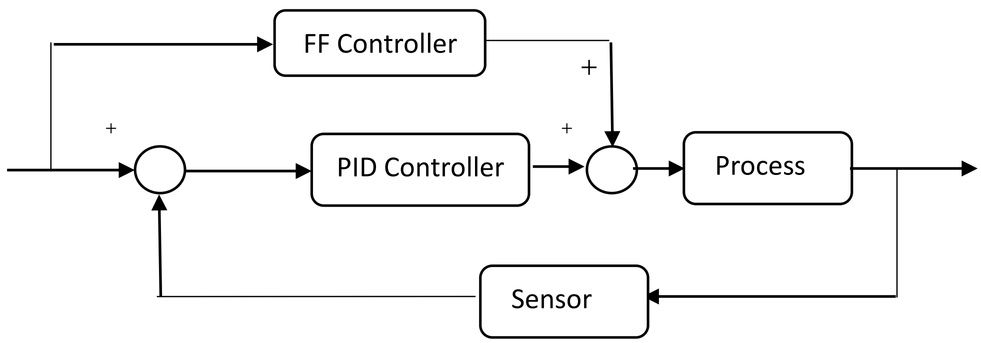


Fig.4: Block diagram of Feed forward along with Feedback PID controllers

There are so many disturbances in this process, but the major disturbance which will effects the process are flow variation of and the variation of input fluid temperature. In feed forward control loop we consider only the disturbance flow variation of input because it is more prominent than the disturbance temperature variation in input fluid. The outputs of the feed forward controller and the feedback PID gets added and the added output is given to the control valve.

First order plus delay time transfer function of heat exchanger is

$$G_p(s) = \frac{0.94}{0.64s+1} e^{-0.0483s}$$

With the feed forward controller we are trying to control the disturbance input flow of fluid. $G_p(s)$ is the process transfer function and $G_d(s)$ is the flow disturbance transfer function.

$$G_d(s) = \frac{1}{1+30s}$$

The feed-forward controller transfer function is given by

$$G_{cf}(s) = \frac{-G_d(s)}{G_p(s)}$$

$$G_{cf}(s) = (30s+1)\frac{0.94}{0.64s+1}e^{-0.0483s}$$

By first order pade approximation

$$e^{-\tau s} = \frac{-\tau s/2+1}{-\tau s/2+1}$$

So

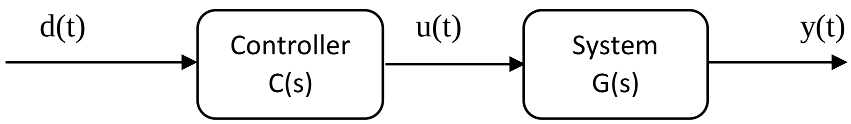
$$G_{cf}(s) = (30s+1)\frac{0.94}{0.64s+1}\frac{-0.024s+1}{0.024s+1}$$

$$G_{cf}(s) = \frac{-0.6768s^2+28.177s+0.94}{0.01536s^2+0.664s+1}$$

Here the above transfer function is Feed forward controller transfer function along with we use the feedback PID controller for a better disturbance rejection.

3.3 Internal Model Controller

The internal model controller is based on internal model principle, which states that efficient control action can be achieved only if the control systems uses some representation of the process to be controlled.



Suppose $\widetilde{G_p}(s)$ is a model of G(s), by selecting C(s) as the model inverse.

$$C(s) = \widetilde{G_p}(s)^{-1}$$

And assuming that $\widetilde{G_p}(s)$= G(s) then the output y(t) will track the reference input d(t) perfectly.

IMC procedure gives a controller which has only single parameter for tuning i.e. IMC filter λ. For a system in 'minimum phase' λ is nothing but the closed loop time constant.

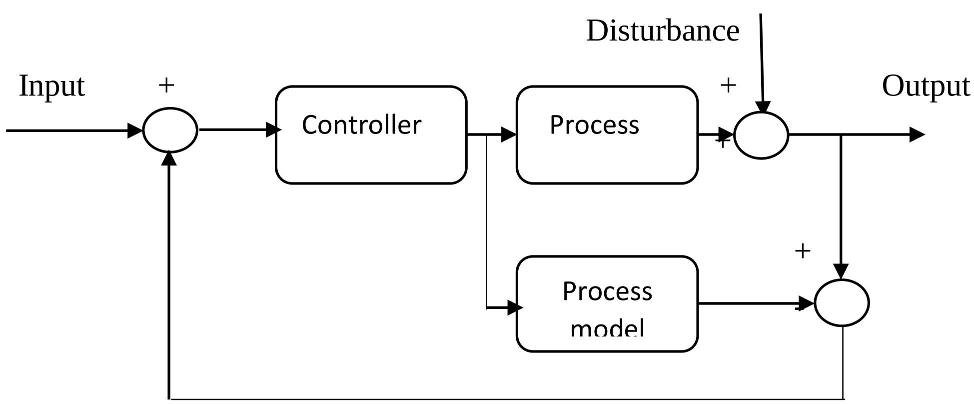


Fig.5: Block diagram of IMC controller

Internal model controller produces the algorithm for design of control system. One of the main feature of internal model controller is the process model and the actual process are in parallel. The transfer function of the process is

$$G_p(s) = \frac{0.94}{0.64s + 1} e^{-0.0483s}$$

By pade approximation transfer function becomes

$$G_p(s) = \frac{0.94}{0.64s+1}\frac{-0.024s+1}{0.024s+1}$$

Divide the process model $G_p(s)$ is in to two parts, non-invertible part $G_{p-}(s)$ and invertible part $G_{p+}(s)$, the part which contains right hand side poles and zeros and time delays are considered as non-invertible, and the remaining part is the invertible part. To make the IMC controller stable this factorization should performed.

$$\widetilde{G_p}(s)=\widetilde{G_{p+}}(s)\ \widetilde{G_{p-}}(s)$$

$$G_{p+}(s) = -0.024s+1 \quad ,$$

$$G_{p-}(s) = \frac{0.94}{(0.64s+1)(0.024s+1)}$$

The IMC controller is given by

$$Q(s) = \widetilde{G_p}(s)^{-1}\ f(s)$$

Where f(s) is the filter used to make the controller as semi proper

$$q(s) = \frac{0.64s+1}{0.94}\frac{0.024s+1}{(\lambda s+1)^2}$$

$$Q(s) = \frac{0.016s^2+0.70s+1.06}{(\lambda s+1)^2}$$

The filter tuning parameter λ is adjusted to vary the closed loop system response speed. If λ is small the closed loop system is fast, and if λ is large the closed loop system is more robust (insensitive to model error).

3.4 IMC-PID Controller

Although IMC procedure is easy to implement and clear, the most commonly used industrial controller is PID controller. The IMC controller can be compared to the standard feedback control to get the tuning parameters for the PID controller.

Internal model control scheme is used to as a conventional feedback PID controller by changing the representation of transfer function. Conventional Feedback PID controller is a function of the internal model controller Q(s) and the process model $\widetilde{G_p}$(s). The transfer function of standard feedback PID controller similar to IMC is

$$G_c(s) = \frac{Q(s)}{1 - G_p(\mathrm{s})Q(s)}$$

For a standard first order dead time process

$$G_p(s) = \frac{K_p}{\tau s + 1} e^{-t_d s}$$

By comparing our heat exchanger system transfer function with the above standard first order delay time process we will get the parameters

K_p =0.94 τ_i =0.64 sec τ_d =0.0483 sec

IMC-PID controller is

$$G_c(s) = \frac{0.5\tau t_d s^2 + (\tau + 0.5t_d)s + 1}{K_p(\lambda + 0.5t_d)s}$$

By comparing with simple PID controllers we will get the tuning parameters as

$$K_c = \frac{\tau + 0.5t_d}{K_p(\lambda + 0.5t_d)}, \qquad \tau_i = \tau + 0.5t_d, \qquad \tau_D = \frac{\tau t_d}{2\tau + t_d}$$

By substituting the above values in the above equations we will get

$K_c = 0.569,\ \tau_I = 0.6645\ sec,\ \tau_D = 0.0232$ sec

The values of PID parameters are

$K_p = 0.569$

$K_i = 0.856$

$K_d = 0.013$

So the transfer function of the IMC-PID controller is given by

$$G_c(s) = 0.565(1 + \frac{1}{0.6645s} + 0.0232s)$$

CHAPTER IV

Design of intelligent PID controllers

In this chapter we are going to study about some intelligent controllers like Fuzzy PID and Fractional order PID controller using particle swarm optimization algorithm.

4.1 Fuzzy Based PID Controller

Fuzzy logic approach is based on computing the degrees of truth. Fuzzy logic is nothing but the human understanding and human thinking. It can be applied to various fields like control theory, artificial intelligence etc. this approach can be effectively utilized when the system is complex where the simple PID controllers cannot.

Fuzzy PID controllers can be designed using fuzzy logic principles. Fuzzy PID controllers are extensions to the simple PID controllers.

Fuzzy PID controller structure as shown. It is similar to simple feedback controller where the inputs to the fuzzy controller are error and the change in error, Output to the fuzzy PID controller is the input to the actuator. The output of the fuzzy controller gets added with the integral of the error i.e. sum of past errors which is the input to the main process. The gains Ge, Gce, Gi has to be tuned for better performance of controllers. The block fuzzy controller uses fuzzy membership functions as shown. So many types of membership functions are available here we used trapezoidal, triangular member ship functions.

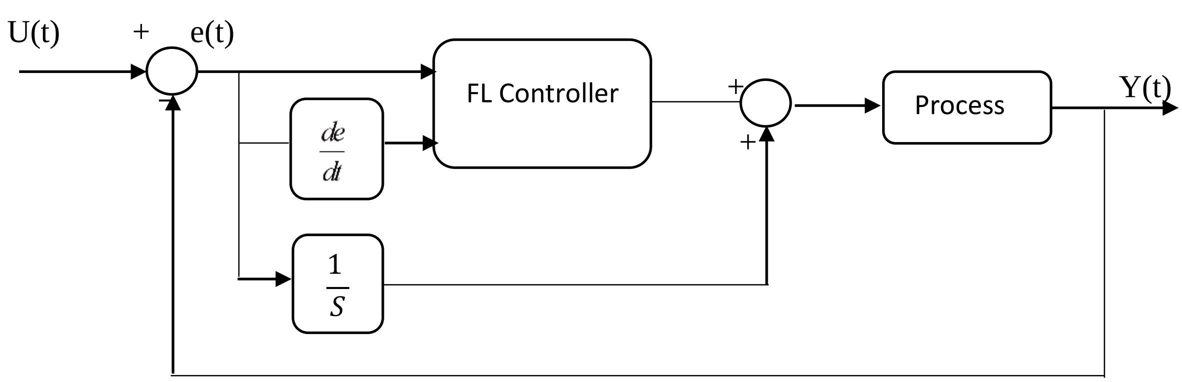


Fig.6: Block diagram of Fuzzy PID controller

This paper using mamdani model of fuzzy controller. In which we used triangular and trapezoidal membership functions. The range of input and outputs are

$-1 < e(t) < 1$, $-1 < \Delta e(t) < 1$, and $-1 < u(t) < 1$

The typical response of the systems is

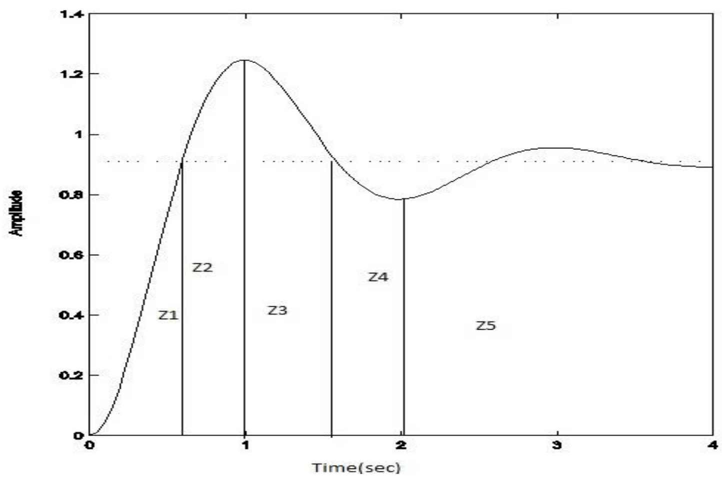


Fig.7: Step response of a first order system

Here the response is divided into five zones according to the sign and magnitude of error and change in error.

In the Zone 1: $e > 0$ and $de < 0$, Zone 2: $e < 0$ and $de < 0$,

Zone 3: $e < 0$ and $de > 0$, Zone 4: $e > 0$ and $de > 0$,

Zone 5: $e \sim 0$ and $de \sim 0$.

In zone1 and zone3 error is self-correcting i.e. approaching to zero so the control action should be same.

In zone2 and zone 4 errors are not self-correcting i.e. tends to increase so the control action should depends on the sign and magnitude of error and change in error.

IN zone5 error and change in error close to zero so no need change the control action we can maintain the previous control setting.

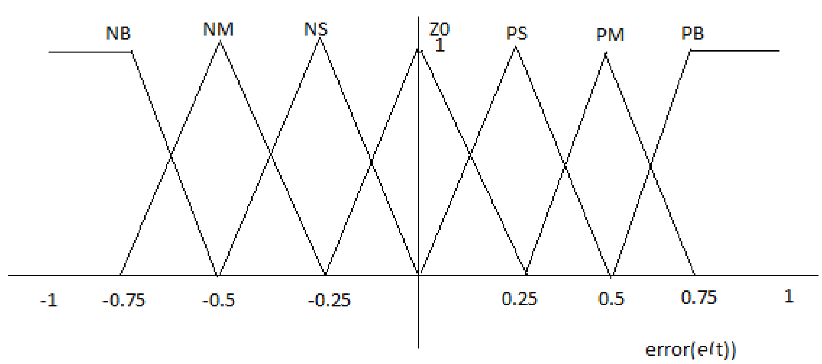
By the above five rules we will take linguistic variables as NB, NM, NS, Z0, PS, PM, PB stands for negative big, Negative medium, negative small, zero, positive small, positive medium and positive big respectively. And the rule base matrix is shown which means when the error is negative big, change in error is negative big the corresponding action has to be the negative big like in the same way 49 rules has to be given to the fuzzy PID controller.

Rule-base matrix for Fuzzy PID controller is described in Table

U(t)		Change in Error ($\Delta e(t)$)						
		NB	NM	NS	Z0	PS	PM	PB
	NB	NB	NB	NB	NB	NM	NS	ZO
	NM	NB	NB	NB	NM	NS	ZO	PS
	NS	NB	NB	NM	NS	ZO	PS	PM
E(t)	ZO	NB	NM	NS	Z0	PS	PM	PB
	PS	NM	NS	Z0	PS	PM	PB	PB
	PM	NS	Z0	PS	PM	PB	PB	PB
	PB	ZO	PS	PM	PB	PB	PB	PB

Table 3: Rule base matrix for fuzzy PID controller

Membership functions for input error and change in errors are



Membership function for output of fuzzy controller is

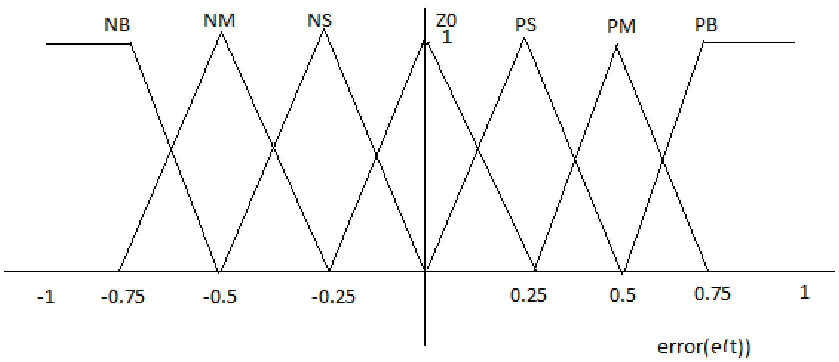


Fig.8: Input and output Membership functions of FLC

4.2 Fractional Order PID Controller Using Particle Swarm Optimization (PSO)

Now a days PID controllers are widely used because of its simple structure and low percentage overshoot but for higher order systems PID controllers are not efficient way to use. To improve the performance of a controllers for a higher order systems we can go for fractional order PID controllers in which the Integral, Derivative parameters are fractional i.e. here in this type of controller the power of ‘S’ for the both derivative, integral terms are fractional. In the simple PID controllers we have to tune the three parameters but in the case of fractional order PID controllers there are five parameters to tune which adds extra two parameters λ and δ are the powers of ‘S’ for the Integral and Derivative terms.

Standard structure of fractional order PID controllers in the S-domain is

$$G_c(s) = K_p + \frac{T_i}{S^{\lambda}} + T_d S^{\delta}$$

If λ=1 and δ=1 it is a simple PID controller

FOPID controllers are comparatively gives the better performance when compared to the conventional PID controllers. The major advantage by using the FOPID controllers is the gives better controller action for a dynamical systems

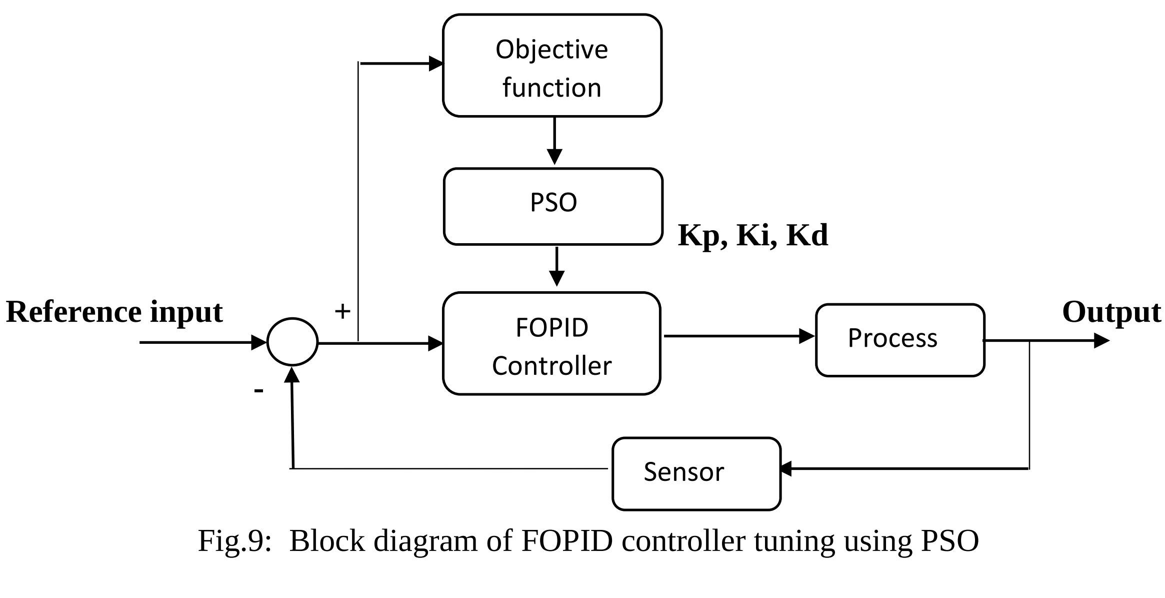


Fig.9: Block diagram of FOPID controller tuning using PSO

4.2.1 Standard PSO algorithm

Particle swarm optimization is a computational method that optimizes the problem by step by step procedure and tries to find the best solution according to the selected objective function. It is inspired from the social behavior of animals such as bird flocking and fish schooling etc.

Here swarm means group of particles, each particle consider as a point in D-dimensional space. Every particle adjusts its position according to the velocity and position of its neighborhood particles. In the PSO algorithm we have to initialize the group of particles with random position and velocities then according to following two equations every time it updates two values Pbest and Gbest where Pbest is the previous best value and Gbest is the best value achieved so far.

$$V_{id}{}^{(t+1)} = wv_{id}{}^{(t)} + c_1 r_1 (p_{id} - x_{id}{}^{(t)}) + c_2 r_2 (p_{gd} - x_{id}{}^{(t)})$$

$$x_{id}{}^{(t+1)} = x_{id}{}^{(t)} + v_{id}{}^{(t+1)}$$

Where $V_{id}{}^{(t)}$ = velocity of ‘i’th particle in‘t‘ th iteration

$x_{id}{}^{(t)}$ =position of ith particle in‘t‘th iteration

c_1, c_2 are the constant weights

w= inertia weight

p_{id} = best position achieved by ith particle

p_{gd} =best position achieved by neighborhood of ith particle

r_1, r_2 are some random values

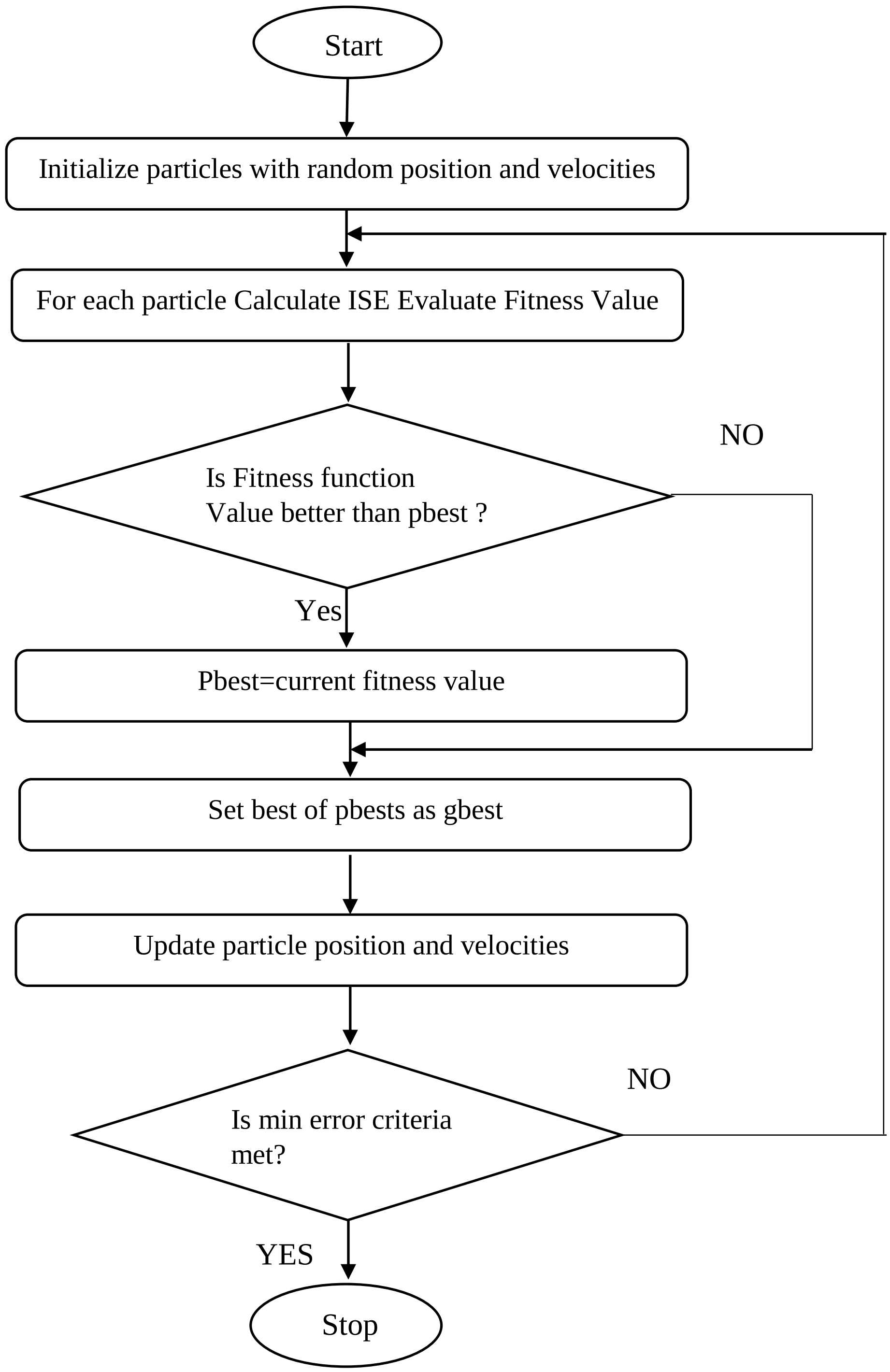


Fig.10: Flowchart for design of PID controller using PSO algorithm

4.2.2 Application of PSO for designing Fractional order PID controllers

PSO parameter selection

Designing of FOPID controller using PSO needs initialization of some parameters. This is the important step in designing the controllers, because the performance of a controllers depends on the initialization, for example if we initialize the parameter with high velocity it may cross the field and more no. of iterations makes the system slower.

Swarm size = 50

No of iterations = 50

Velocity constant, C1 = 1.2

Velocity constant, C2 = 0.12

Inertia weight w= 0.9

Selection of objective function

The objective function considered here depending on the error criterion. The controller performance is evaluated based on error criterion. Here in this work considered three such type of error criterion namely IAE, ISE, and ITAE.

Integral of Absolute Error (IAE), given by

$$IAE = \int_{o}^{T} |\, e(t) \,|\, dt$$

IAE is the integration of the absolute error over a particular time. It doesn't add weight to any of the errors in a systems response. It produces the slower response when compared to ISE optimal systems, but with minimum oscillations.

Integral Square Error (ISE) mathematical representation is

$$ISE = \int_{o}^{T} e^{2}(t)dt$$

ISE is the integration of the square of the error over a particular time. It considers large errors more than smaller ones (the square of the error will become much larger). The systems which are specified to remove ISE will eliminates large errors quickly, but the small errors may not be minimized quickly it persist for a certain period. So this leads to fast response, but the amplitude, oscillation are less.

Integral over Time multiplied by Absolute Errors (ITAE) represented as

$$ITAE = \int_{o}^{T} t\,|\,e(t)\,|\,dt$$

ITAE is the integration of the absolute error multiplied by the time over a particular time. ITAE minimizes the weight errors which exist for a certain time than the errors at the initial response. By using ITAE tuning we can bring systems settling time very less compared to the other two tuning methods. But with this ITAE tuning the system response is sluggish.

The time is considered as, t=0 to T, where ‘T’ is the settling time of the system when it is in steady state condition for a given unit step input.

Termination Criteria

Optimization algorithm can terminate either when the number of iterations reached to the maximum extent or when approaching to the satisfactory fitness value. Here in this case we consider for an optimization of objective function so the fitness value is the reciprocal of the magnitude of the objective function. In this paper we considered the termination criteria as the attainment of satisfactory fitness value which occurs at the maximum number of iteration here it is 100^{th} iteration. For every iteration the best value in the 100 particles is considered as best solution and it is selected as the best value among the 100 particles.

In the fractional order PID controller we have to tune the five parameters, we can first consider the PID parameters from either Ziegler Nichols tuning method or the PID tuning using the same above PSO algorithm and then by selecting the three parameters just by either way above mentioned calculate the parameters from the PSO algorithm. According the selected objective function PSO algorithm produces the five parameters. We can select ISE, IAE, and ITAE as objective functions for a better controller action. The error value decreases when approaching to the large no of iterations. In this paper selected no of iterations are 50, so the values of PID parameters after 50 iterations are the final tuned parameters of fractional PID controller.

We observer that for large no. of iterations the error value gets optimized. But after 50 iterations the change is quite small, which is less considerable. Because of that reason no. of iterations are limited 50.

For ISE as objective function the controller transfer function is

$$G_c(s) = 0.8425 + \frac{0.0012}{S^{2.4963}} + 0.4955S^{1.2668}$$

For IAE as objective function obtained controller transfer function is

$$G_c(s) = 0.8425 + \frac{0.0012}{S^{1.7495}} + 0.4955S^{1.2589}$$

For IAE as objective function obtained controller transfer function is

$$G_c(s) = 0.8425 + \frac{0.0012}{S^{2.2898}} + 0.4955S^{0.4964}$$

CHAPTER V

Results and discussions

The simulations for the different controllers are carried out in MATLAB SIMULINK and the results have been obtained.

5.1 Feedback and Feedforward controllers

Fig1 shows the comparison of step responses of heat exchanger with feedback PID controller and the Feed forward plus feedback PID controller. At first the set point is 5 and then at 100sec we changed the set point to 10, for the PID controller overshoot is high on adding feed forward control by considering flow disturbance percentage overshoot reduced.

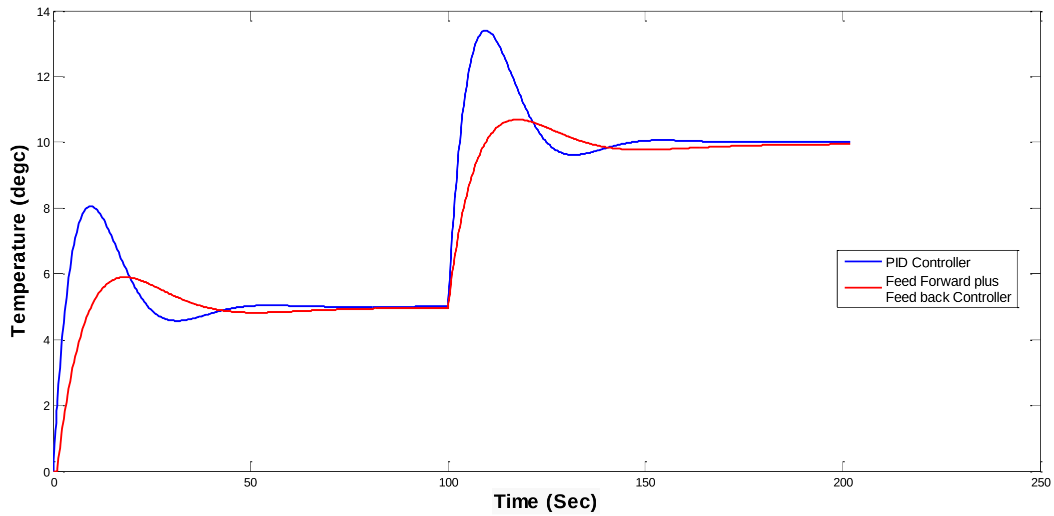


Fig.11: Step response of Heat exchanger with PID, Feed Forward plus Feedback PID controllers for a set point change

By applying the disturbance at 100sec the set point has been changed and it is tracked i.e. reaches to steady state after 150 sec, means the recovery time for the PID controller is better than the feedforward plus feedback PID controller. But in the PID controller response oscillations is more which changes the system to unstable state.

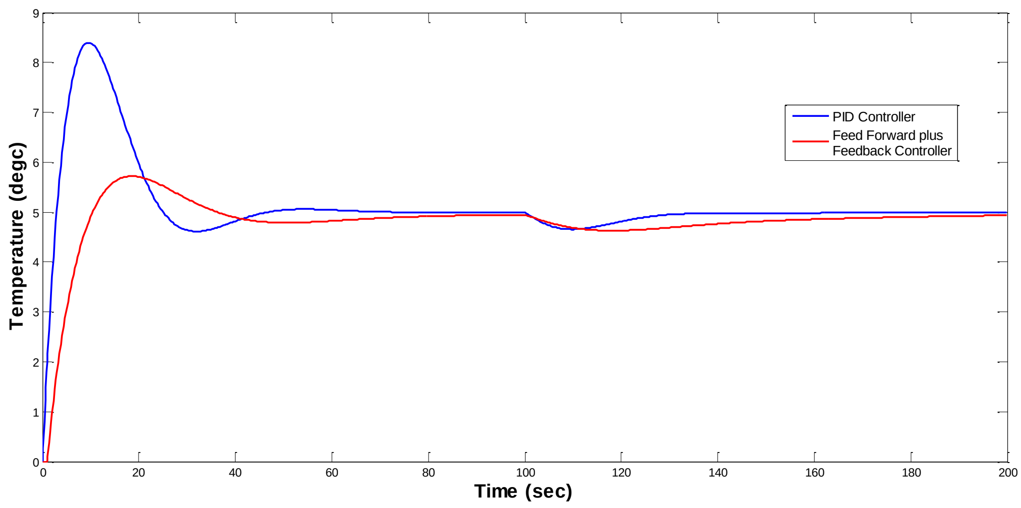
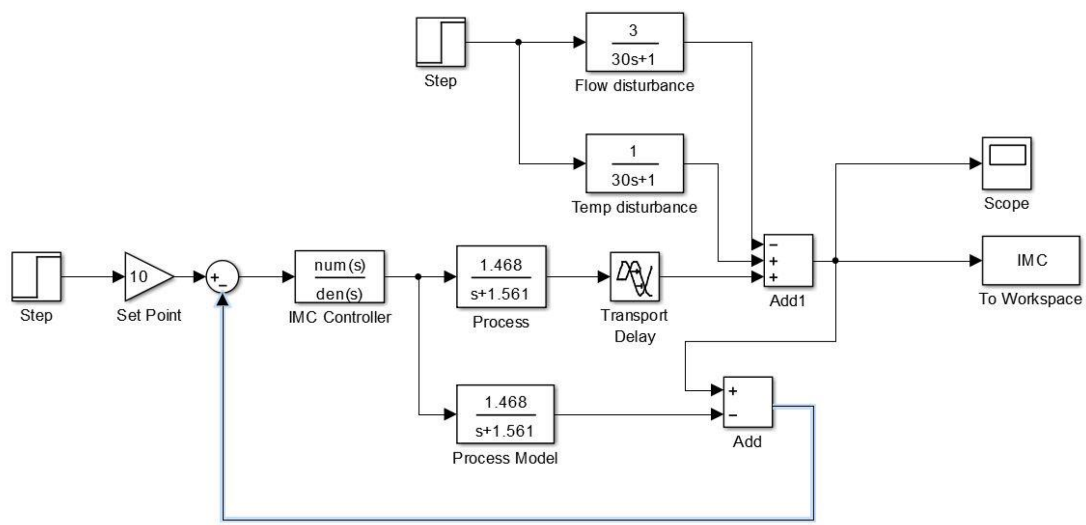


Fig.11: Step response of Heat exchanger with PID, Feed Forward plus Feedback PID controllers when the disturbance applied at 100sec

5.2 IMC controller

Fig shows the MATLAB Simulink model of heat exchanger with IMC controller here the process model is the transfer function of heat exchanger obtained from the system identification experiment and the process is the same transfer function but with the time delay. We consider two disturbances flow and the temperature disturbances.



As shown the response of heat exchanger with IMC controller here as there are no oscillations in the response the percentage overshoot is completely eliminated but the rise time is increased. Response when disturbance applied at 100sec also shown, recovery time is large when compared to the PID controllers.

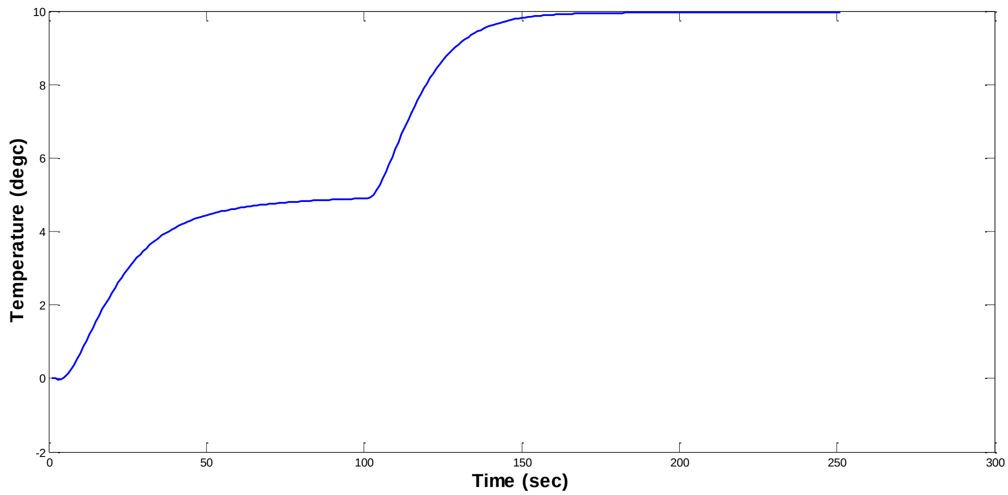


Fig.12: Step response of Heat exchanger with IMC controller for a set point change

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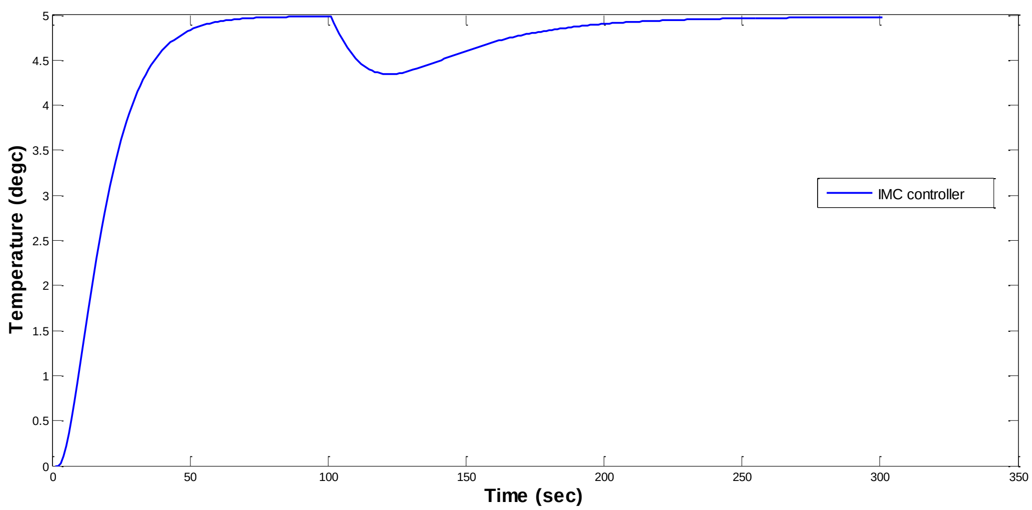


Fig.12: Step response of Heat exchanger with IMC controller when the disturbance applied at 100sec

5.3 IMC PID Controller

IMC and IMC-PID controllers are almost similar. Representation of IMC-PID controllers is different from the IMC controller. There is no much difference between the performances of these two controllers

As shown the responses of step input change and disturbance rejection of IMC- PID controller are almost similar to the IMC controller

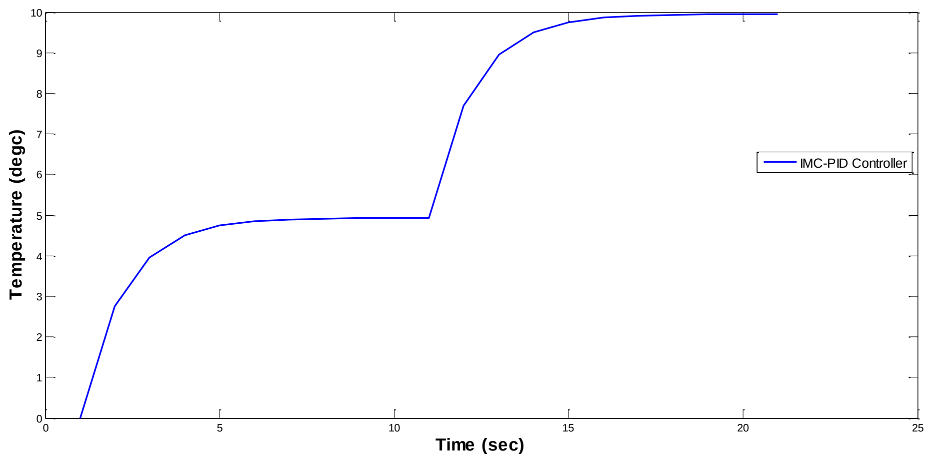


Fig.13: Step response of Heat exchanger with IMC-PID controller for a set point change

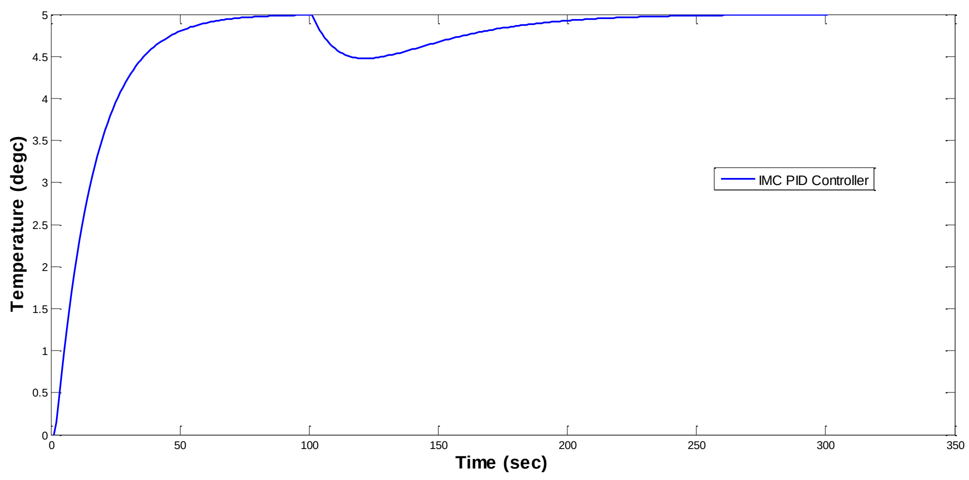
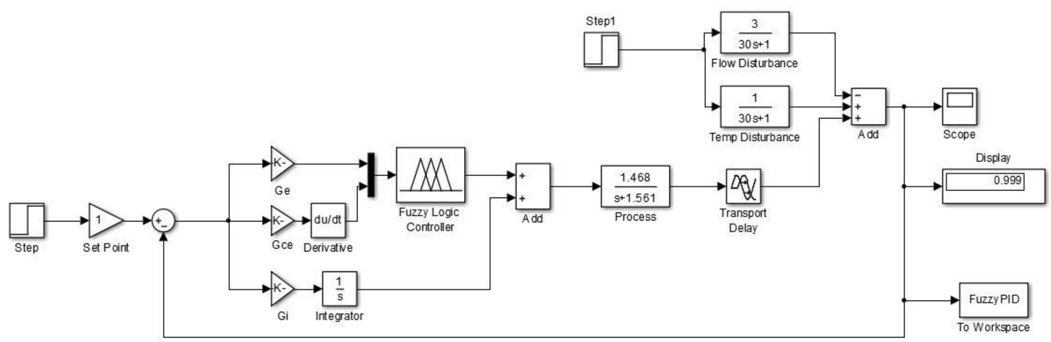


Fig. Step response of Heat exchanger with IMCPID controller when disturbance applied at 100sec

5.4 Fuzzy PID controller

Simulink model of fuzzy PID controller is shown here the block fuzzy logic controller has inputs error and change in error. And then the output of fuzzy controller is added with the integrated error which is the input to the process.



Step response of heat exchanger with the fuzzy PID controller is shown overshoot is completely eliminated but the rise time is quite high when compared to the other conventional controllers like PID controller. But the change in set point at 125sec is tracked in just 25sec means its recovery time is less.

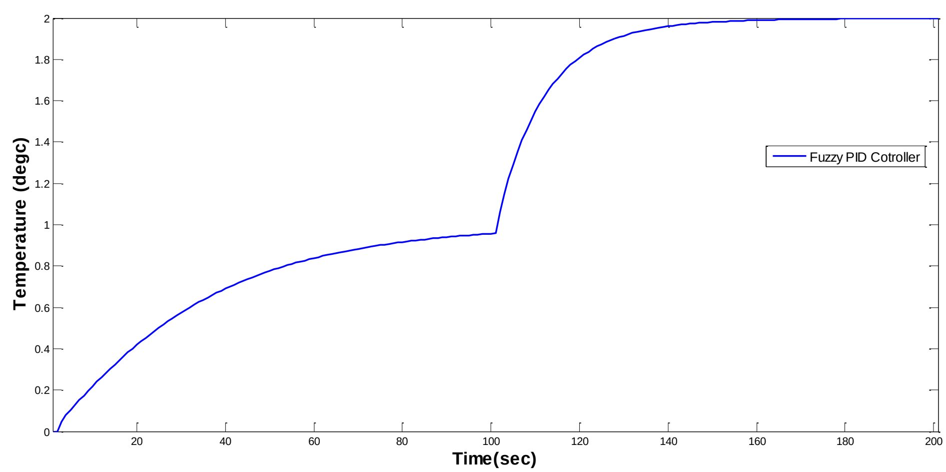


Fig.14: Step response of Heat exchanger with IMC-PID controller for a set point change

Step response of heat exchanger with the Fuzzy PID controller is shown, the disturbance applied at 100sec due to that some set point drop occurred but in almost 50sec it is again tracking the set point. Which is better response when compared to the IMC, IMC-PID controllers.

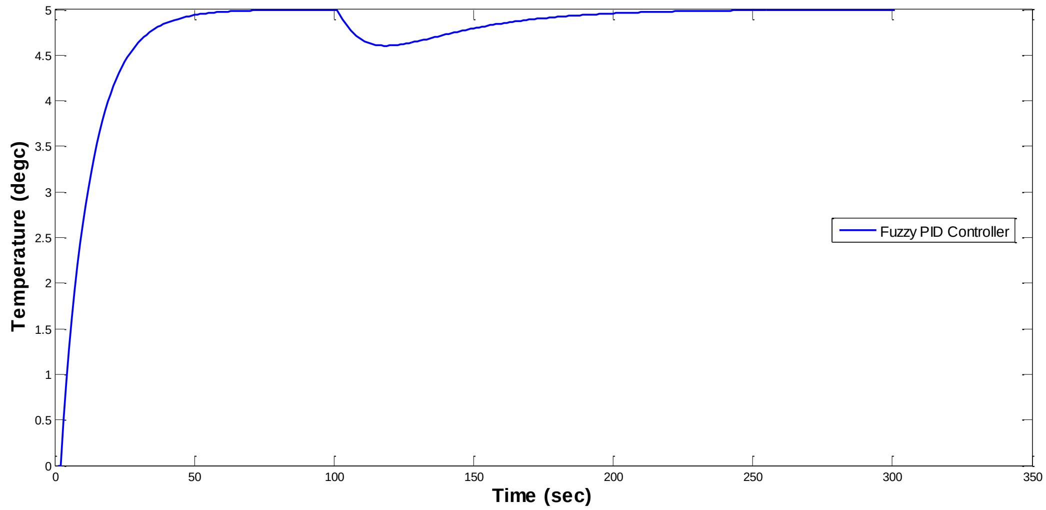
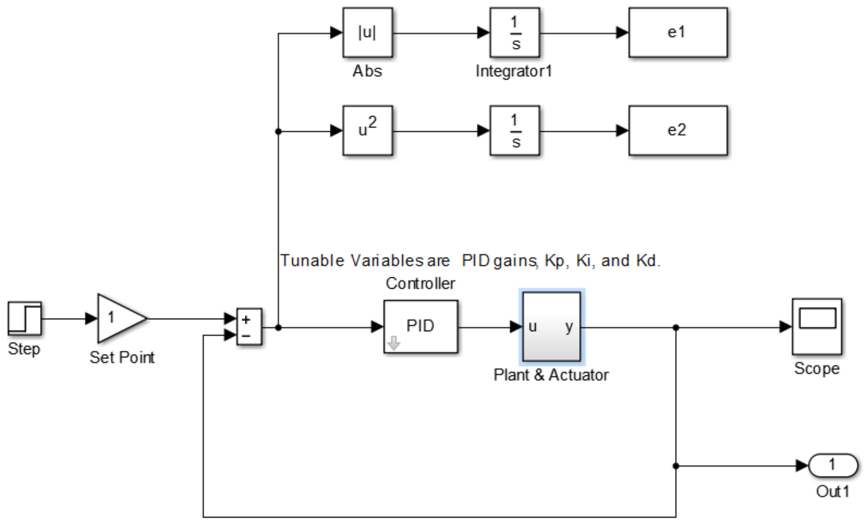


Fig.14 Step response of Heat exchanger with Fuzzy logic based PID controller when disturbance applied at 100sec

5.5 FOPID Controller

Simulink model of FOPID controller is shown here the FOPID controller back has five tuning parameters which are updated for every iteration through PSO algorithm.



Step response of heat exchanger with the FOPID controller is shown settling time is very less in this type of controller, and also rise time is quite low when compared to the other conventional controllers like PID controller. Shown response is the step response of FOPID controller by considering the objective function as ISE.

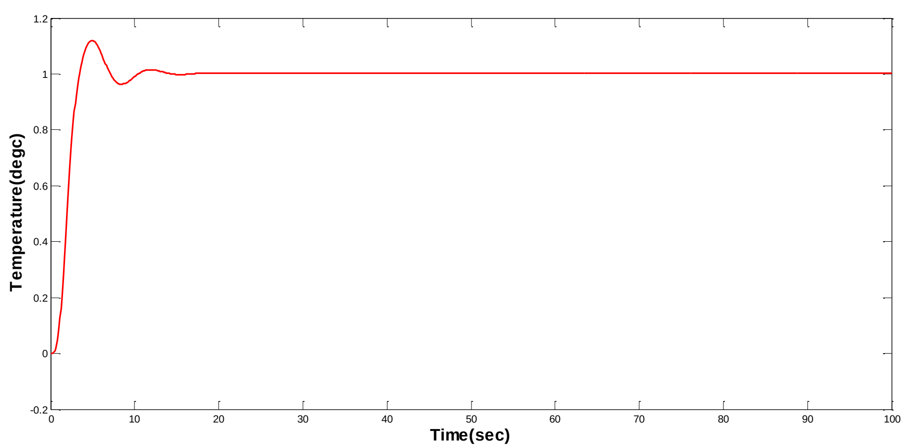


Fig.15: step response of heat exchanger with FOPID controller with ISE as objective function

The response comparisons of FOPID controller with the objective function selected as ISE, IAE. We can observed the response ISE is more prominent than the IAE error criteria. Because in the IAE error may be eliminated.

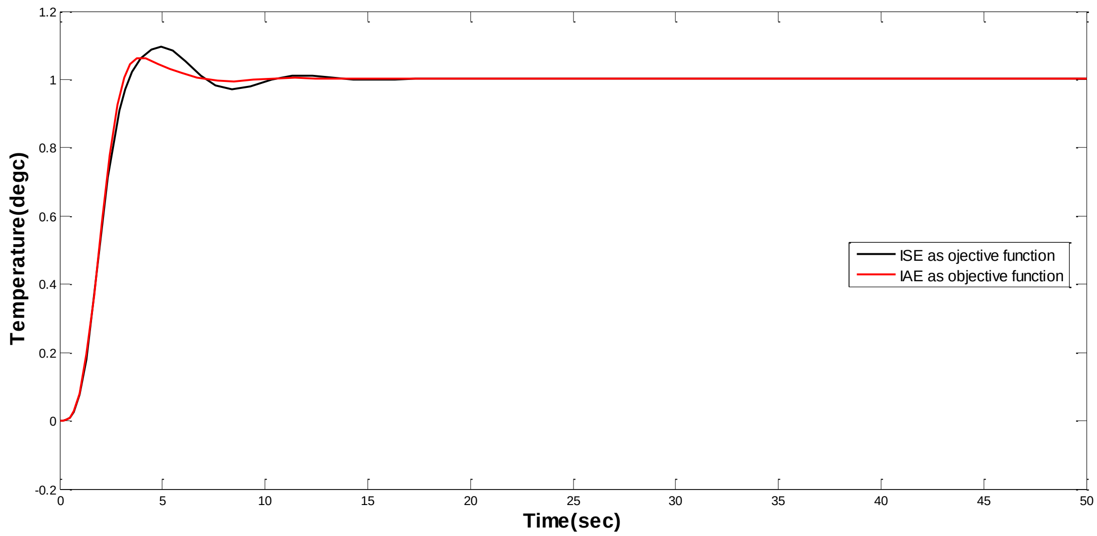


Fig.15: Step response of heat exchanger with FOPID controller with IAE, ISE as objective function

The performance evaluation of heat exchanger with the different controllers is shown in the table by considering some time response specification like Rise time, Settling time, Overshoot and also the errors ISE and IAE.

S. No	Controller	Rise time	Settling time	Overshoot	ISE	IAE
1	Feedback PID	3.07	83.36	39.37	0.1435	1.758
2	Feedback plus Feed Forward	5.25	85.12	22.16	0.1841	2.079
3	IMC	5.05	83.58	6	0.8326	4.213
4	IMC PID	5.13	82.42	0	0.7784	3.733
5	Fuzzy PID	4.23	75.19	0	16.14	31.86
6	FOPID	10.36	35.36	15.49	0.1236	0.5632

Table 4: Comparison of time response specifications for various controllers

As shown in the table with the Feedback PID controller we get max overshoot of 39.37% it is reduced by using feedforward controller and also it can be completely eliminated by IMCPID controller and Fuzzy PID controller. FOPID controller gives some overshoot but the rise time and settling time are much improved compared to the others. By employing FOPID controller using PSO the errors ISE, IAE are completely reduced as the objective function in the PSO algorithm is error.

CHAPTER VI

Conclusions

6.1 Conclusions

Transfer function of heat exchanger obtained using system identification method. And different controllers including conventional and intelligent controllers are design for the obtained transfer function i.e. for a temperature control of heat exchanger. And it is observed that Feedback PID controller produces very high peak overshoot, feed forward controller along with the conventional PID in feedback path is implemented for the compensation of high peak overshoot. By implementing IMC PID and Fuzzy PID controller overshoot can be totally eliminated. Compared to the feedback controller the settling time of response was reduced by using feed forward plus feedback PID controller. The designed FOPID controller using PSO algorithm shows superior performance over the traditional method of Ziegler-Nichols, in terms of the system overshoot, settling time and rise time.

6.2 Future work

1. Discussed control laws can be implemented for higher order systems.
2. Different Genetic algorithm based optimization can be applied for the tuning of PID controller as well as FOPID controllers.

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